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Original Article

# PERFORMANCE COMPARISON OF ELECTRICAL PARAMETERS BETWEEN GANFINFET AND SI-FINFET NANO DEVICES

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***ABSTRACT***

***Gallium Nitride (GaN) has been widely used as stressor in channel region of Metal-Oxide-Semiconductor Field Effect Transistor (MOSFET) rather than Silicon (Si) to enhance the channel mobility. In nanoelectronic devices, the GaNFinFETs are also widely used than Si-FinFETs. In this paper, the effects of variations of electrical parameters such as energy band diagram, electrical field, subthreshold swing (SS), transconductance, I-V characteristics and leakage current for both GaNFinFET and Si-FinFET by using the 8nm channel length have been compared and carefully observed that 8nm channel length of GaNFinFET has shown better electrical performances than 8nm channel length of Si-FinFET. Then the impacts of variations of channel length on leakage current, transconductance and I-V characteristics have been shown successfully. The leakage currents by using 8nm and 10nm channel length of both GaNFinFET and Si-FinFET have been measured and found more reduced leakage current of 8nm channel length of GaNFinFET. Finally, transconductance and I-V characteristic of 8nm and 10nm channel length of GaN have been also analyzed and observed better transconductance and drain current performances for 8nm channel length of GaNFinFET. For better performance, online based multigate FET (MuGFET) resource of nanoHUB.org simulator software has been used. All accurate related values of electrical parameters have been collected by using online based simulator tool nanoHUB.org. For precise analyses, a statistical method and Fermi level equation of nanoHUB.org simulator have been used. For better electrical performances of 8nm channel length of GaNFinFET than Si-FinFETmust be used to design future Nano Devices.***

***KEYWORDS: GaNFinFET, Si-FinFET, Channel Length, Electrical Parameters & Leakage Current***

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## 1. INTRODUCTION

We have tried to find better heterojunction III-V material based channel for comparing several electrical parameter like electric field, subthreshold swing (SS), transconductance, I-V characteristic, etc. with single material based channel like silicon. We have seen that GaN channel is more useable than silicon channel. The GaN has wide band gap of 3.4 eV affords its special properties for applications in optoelectronic high-power and high-frequency devices [1][2]. GaN is a very hard (12±2 GPa [3]), mechanically stable wide bandgap semiconductor material with high heat capacity and thermal conductivity [4], but we have found that the GaN is better channel material than Si-FinFET. Military and space applications could also benefit as devices have shown stability in

radiation environments [5]. The GaN offers promising characteristics for GHz/THz devices [6][7]. The first GaN metal oxide semiconductor field-effect transistors were experimentally demonstrated in 1993 [8] and they are being actively developed. In 2010 the first enhancement-mode gallium nitride transistors became generally available [9]. The very high breakdown voltages, high electron mobility and saturation velocity of GaN have also made it an ideal candidate for high-power and high-temperature microwave applications [10]. The GaN can be doped with silicon (Si) or with oxygen[11] to n-type and with magnesium (Mg) to p-type[12]. However, the Si and Mg atoms change the way of GaN crystals grow, introducing tensile stresses and making them brittle [13]. We have shown the performance comparisons of energy band diagram, electric field, subthreshold swing, transconductance, I-V characteristic and leakage current by using 8nm channel length of GaNFinFET with Si-FinFET. Finally, leakage current for both GaNFinFET and Si-FinFET using 8nm and 10nm channel length; transconductance and short channel effects of I-V characteristic of 8nm and 10nm channel length of GaN have been demonstrated.

## 2. METHODS

We have used nanoHUB.org simulator software to find accurate analytical result. The analytical result depends on Fermi label equation that is used by NanoHUB.org tool.

$$f(E) = \frac{1}{e^{(E - E_F)/kT} + 1} \tag{1}$$

The NanoHUB.org is an online base simulator software which is widely used. To get accurate result, at first we have collected the approximate data table for the material that used as a channel. Then the different related parameters have included into blank fields of the simulator. After simulation process, we have collected data from the curves connected with online and then the data also included into the Origin Lab simulator software. Finally, the comparison curves have designed perfectly by PowerPoint software.

## 3. RESULTS AND DISCUSSIONS

### 3.1. Comparison of Energy Band Diagram between GaNFinFET and Si-FinFET

**Table 1: Data for Energy Band Diagram of 8nm Channel Length of GaNFinFET and Si-FinFET**

| Gate Length | Energy(eV) | Energy(eV) |
|---|---|---|
| (μm) | Energy band diagram of 8nm channel length of GaNFinFET | Energy band diagram of 8nm channel length of Si- FinFET |
| 0 | | |
| 0.0192 | 0.57408 | 0.02722 |
| 0.02254 | 0.57129 | 0.02722 |
| 0.03018 | 0.56506 | 0.02723 |
| 0.03646 | 0.56061 | 0.02723 |
| 0.04266 | 0.55841 | 0.0274 |
| 0.04622 | 0.55851 | 0.03195 |
| 0.05072 | 0.5606 | 0.12922 |
| 0.05406 | 0.56396 | 0.19481 |
| 0.05699 | 0.5686 | 0.23223 |
| 0.05969 | 0.57475 | 0.26074 |
| 0.07431 | 0.66738 | 0.32228 |
| 0.07734 | 0.70516 | 0.30922 |
| 0.08058 | 0.7444 | 0.27553 |
| 0.08461 | 0.7444 | 0.22732 |
| 0.08708 | 0.79913 | 0.17099 |
| 0.08993 | 0.83355 | 0.13759 |

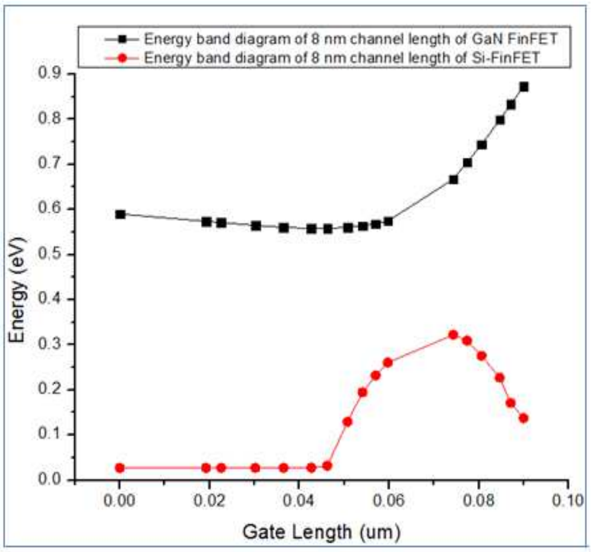


**Figure 1: Comparison of Energy Band Diagram of 8nm Channel Length of GaNFinFET and Si-FinFET**

GaN is a compound material that is widely used for nano devices. Though the compound materials will face some critical problem like missmatch, high dislocation density, but if we compare several electrical properties like energy band diagram, electric field, subthreshold swing etc. between compound material and single material then we have seen that compound material is better than single material.

From the Figure 1, we have observed that if we increase the gate length of Si-FinFET and GaNFinFET, the energy of GaNFinFET increases sequentially on the other hand the energy of Si FinFET firstly increases and then decreases for large gate length. So, we must have choosen8nm channel length of GaN because of sequential current flow whereas Si-FinFET of same channel length current flows randomly. Perfect current flows can save an electrical device from heat that we can get from GaNFinFET of 8nm channel length.

### 3.2. Comparison of Electric Field between GaNFinFETand Si-FinFET

**Table 2: Data for Electric Field of 8nm Channel Length of GaNFinFET and Si-FinFET**

| Gate length | Electric Field(V/cm) | Electric Field(V/cm) |
|---|---|---|
| µm | Electric Field of 8nm channel length of GaNFinFET | Electric Field of 8nm channel length of Si FinFET |
| 0 | -8348.28 | -6.40086E-4 |
| 0.01093 | -8333.8 | -0.00776 |
| 0.0192 | -8328.99 | -0.00258 |
| 0.02254 | -8300.5 | -0.09184 |
| 0.02798 | -8079.73 | -0.44796 |
| 0.03209 | -7488.73 | -2.76703 |
| 0.04427 | -91.9802 | -5254.33 |
| 0.04472 | -534.874 | -14984.1 |
| 0.04622 | -2069.08 | -36953.5 |
| 0.0486 | -4752.25 | -131180 |
| 0.05 | -6490 | -217376 |
| 0.05149 | -8616 | -165203 |
| 0.05501 | -14725.3 | -152298 |
| 0.056 | -16840.5 | -145155 |
| 0.05699 | -19172.6 | -120970 |
| 0.05969 | -26837.6 | -92787.2 |

| Table 2: Contd., | | |
|---|---|---|
| 0.06128 | -32433.3 | -71884.4 |
| 0.0634 | -41333.2 | -60805.5 |
| 0.06465 | -53544.8 | -49296.4 |
| 0.06578 | -59533.1 | -37335.8 |
| 0.0668 | -70775 | -24889.4 |
| 0.0697 | -78300.5 | -11907.3 |
| 0.07007 | -84924 | -1674.88 |
| 0.0735 | -103661 | -28269.3 |

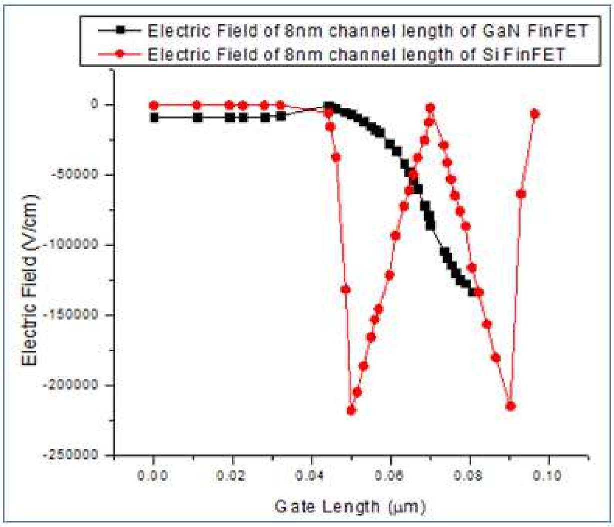


**Figure 2: Comparison of Electric Field of 8nm Channel Length of GaNFinFET and Si-FinFET**

The electric field is the most important parameter of electrical devices. The high electric field can produce perfect current flow and we can get it from GaNFinFET. In the Figure 2, we have shown that if we increase the gate length for both Si-FinFET and GaNFinFET where channel length is 8nm, the 8nm channel length of Si-FinFET generates “W” shape fluctuating curve of electric field but the electric field of 8nm channel length of GaN decreases sequentially with high gate length. If we use 8nm channel length of GaN it makes better electric field property than 8nm channel length of silicon FinFET.

### 3.3. Comparison of Subthreshold Swing (ss) between GaNFinFET and Si-FinFET

**Table 3: Data forSubthreshold Swing (ss) of 8nm Channel Length of GaNFinFET and Si-FinFET**

| Drain Voltage | Subthreshold Swing(mV/dec) | Subthreshold Swing(mV/dec) |
|---|---|---|
| V | Subthreshold Swing of 8nm channel length of Si FinFET | Subthreshold Swing of 8nm channel length of GaNFinFET |
| 0.05 | 105.047 | 0 |
| 0.2875 | 110 | 2224.78 |
| 0.525 | 117.09 | 2018.03 |
| 0.7625 | 121.07 | 6450.18 |
| 1 | 129.12 | 77140 |

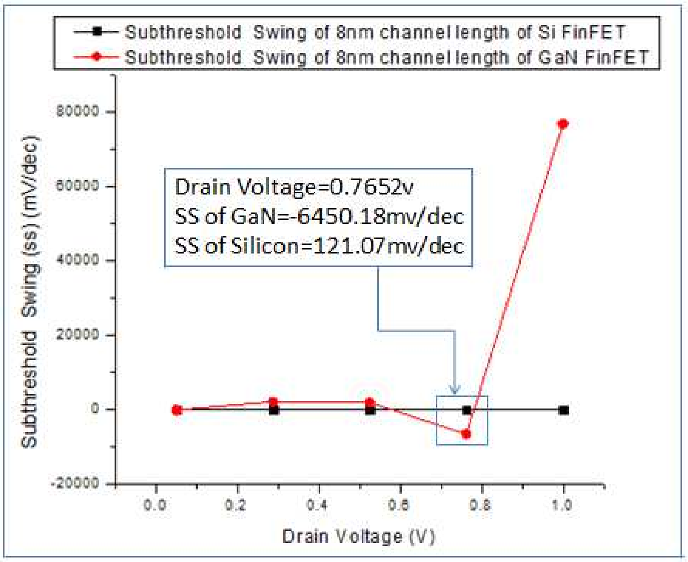


**Figure 3: Comparison of Subthreshold Swing (ss) of 8nm Channel Length of GaNFinFET and Si-FinFET.**

In the Figure 3, we have shown that the subthreshold swing of 8nm channel length of GaN is minus 6450.18 mV/dec at 0.7625V of drain voltage, but at that point the subthreshold swing of 8nm channel length of Si-FinFET is 121.07 mV/dec. We know that subthreshold swing (SS) is closely related to leakage current and we get more leakage current if the subthreshold swing is high. So, at the point 0.7625V, we have detected more leakage current of 8nm channel length of Si-FinFET because of high subthreshold swing (SS). So, we can choose exactly 0.7625V drain voltage for 8nm channel length of GaNFinFET because of low subthreshold swing.

### 3.4. Comparison of Transconductance between GaNFinFETand Si-FinFET

**Table 4: Data for Transconductance of 8nm Channel Length of GaNFinFET and Si-FinFET**

| Drain Voltage | Transconductance(S/µm) | Transconductance(S/µm) |
|---|---|---|
| V | Transconductance of 8nm channel length of Si FinFET | Transconductance of 8nm channel length of GaNFinFET |
| 0.10714 | 1.93502E-6 | -4.81299E-14 |
| 0.17857 | 3.29541E-6 | 4.66359E-14 |
| 0.25 | 7.97986E-5 | 4.55689E-14 |
| 0.32143 | 2.15056E-4 | 3.95912E-14 |
| 0.39286 | 4.9321E-4 | 3.08032E-14 |
| 0.46429 | 5.9551E-4 | 2.28266E-14 |
| 0.53571 | 5.3221E-4 | 1.66962E-14 |
| 0.60743 | 4.2021E-4 | 1.27626E-14 |
| 0.67857 | 1.5032E-4 | 9.90615E-15 |
| 0.75 | 7.81072E-5 | 7.9065E-15 |
| 0.82143 | 3.15412E-6 | 6.47582E-15 |
| 0.89286 | 2.58142E-6 | 5.427E-15 |

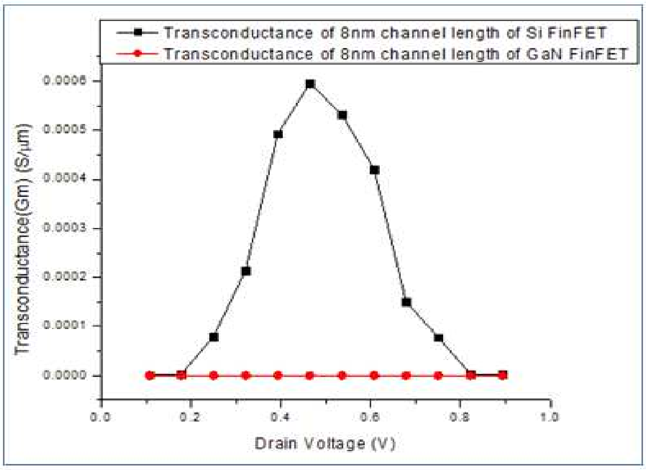


**Figure 4: Comparison of Transconductance of 8nm Channel Length of GaNFinFET and Si-FinFET**

In the Figure 4, we have noticed that if we increase the drain voltages of 8nm channel length of Si-FinFET, the transconductance increases firstly and then decreases, on the other hand transconductance of 8nm channel length of GaNFinFET increases sequentially. So, for the large variation of transconductance of 8nm channel length of Si-FinFET will generate random current flow into channel which is harmful for our nano devices. We must use 8nm channel length of GaNFinFET if we want to design a suitable electrical device.

### 3.5. Comparison of I-V Characteristic of GaNFinFET and Si-FinFET

**Table 5: Data for I-V characteristic of 8nm Channel Length of GaNFinFET and Si- FinFET**

| Gate Voltage | Drain Current(A/µm) | Drain Current(A/µm) |
|---|---|---|
| V | IV Characteristic of 8nm channel length of Si FinFET | IV Characteristic of 8nm channel length of GaNFinFET |
| 0 | 1.66163E-8 | 1.43224E-17 |
| 0.07143 | 1.54708E-7 | 1.53002E-17 |
| 0.14286 | 1.3336E-6 | 1.63014E-17 |
| 0.21429 | 5.5763E-6 | 1.72987E-17 |
| 0.28571 | 7.7584E-6 | 1.82447E-17 |
| 0.35714 | 7.05612E-5 | 1.90787E-17 |
| 0.42857 | 1.02899E-4 | 1.97679E-17 |
| 0.5 | 1.25778E-4 | 2.0317E-17 |
| 0.57143 | 1.52595E-4 | 2.07495E-17 |
| 0.64286 | 1.74801E-4 | 2.10917E-17 |
| 0.71429 | 1.79986E-4 | 2.13665E-17 |
| 0.78571 | 1.82611E-4 | 2.15912E-17 |
| 0.85714 | 1.85998E-4 | 2.17785E-17 |
| 0.92857 | 1.87903E-4 | 2.19375E-17 |
| 1 | 1.89705E-4 | 2.20747E-17 |

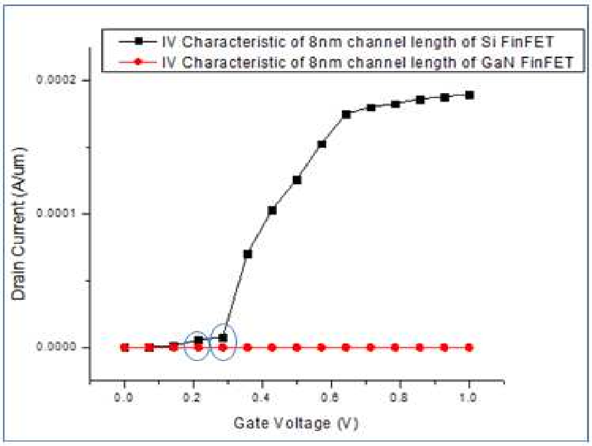


**Figure 5: Comparison of I-V Characteristic of 8nm Channel Length of GaNFinFET and Si- FinFET**

I-V characteristic is such kind of electrical parameter that easily can say which material or compound material is better for nano devices. In Figure 5, we have identified that the I-V characteristic curve of 8nm channel length of GaNFinFET increases smoothly according to gate voltage other hand the I-V characteristic curve of 8nm channel length of Si-FinFET increases randomly which is evil for nano devices because of random current flow. If we want to get consummate electrical device, we must be used GaN as a channel material where channel length is 8nm.

## 4. DESIGN CHANNEL LENGTH VARIATION MODELS OF GaNFOR REDUCED LEAKAGE CURRENT

Mainly we have focused here

- Nano channel length: we have used 8nm channel length of GaNto get low leakage current.
- We have also used 10nm source and drain length that compressed our device to find out better electrical performance.

In Figure 6, the Nano Structures of device where we have used GaN as Channel material and channel lengths are 8nm and 10nm respectively.

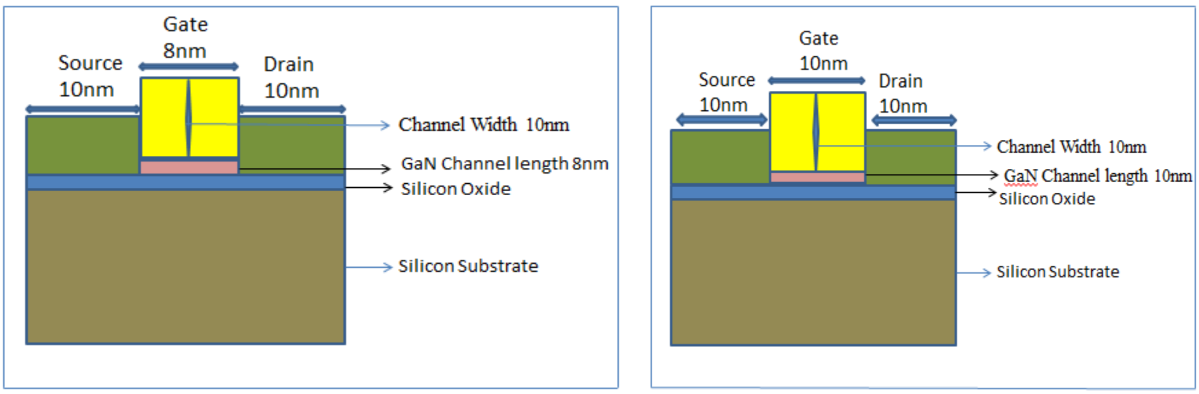


**Figure 6: Nano Structure of Electrical Device used 8nm and 10nm Channel Length of GaN**

## 5. IMPACTS OF VARIATIONS OF CHANNEL LENGTH ON ELECTRICAL PARAMETERS

### 5.1. Comparison of Subthreshold Swing of both GaNFinFET and Si-FinFET using 8nm and 10 nm Channel lengths

**Table 6: Data for Subthreshold Swing of 8nm and 10nm Channel Length of GaNFinFET and Si-FinFET**

| Drain Voltage | Subthreshold swing(mV/dec) | Subthreshold swing(mV/dec) | Subthreshold swing(mV/dec) | Subthreshold swing(mV/dec) |
|---|---|---|---|---|
| V | Subthreshold Swing of 8nm channel length of GaNFinFET | Subthreshold Swing of 8nm channel length of Si FinFET | Subthreshold Swing of 10nm channel length of Si FinFET | Subthreshold Swing of 10nm channel length of GaNFinFET |
| 0.05 | 0 | 105.047 | 66.4133 | 0 |
| 0.2875 | 2224.78 | 110 | 715.152 | 2147.44 |
| 0.525 | 2018.03 | 117.09 | 575.165 | 1928.53 |
| 0.7625 | -6450.18 | 121.07 | 280.56 | -3349.87 |
| 1 | 77140 | 129.12 | 185.285 | 77714 |

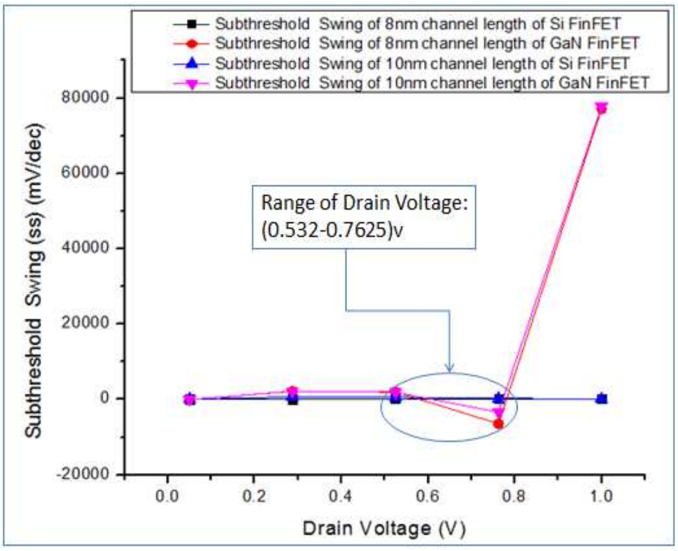


**Figure 7: Comparison of Subthreshold Swing of 8nm and 10nm Channel Length of GaNFinFET and Si-FinFET**

In Figure 7, we have examined that the leakage currents by using 8nm and 10nm channel length of GaNFinFET and Si-FinFET. We have observed that the subthreshold swing of 8nm channel length of GaNFinFET at 0.532-0.7625V range of drain voltage is lowest than others. So, the lowest subthreshold swing of GaN of 8nm channel length generates more less leakage current which is excellent to design a robust nano device.

### 5.2. Comparison of Transconductance of 8nm and 10nm Channel Length of GaNFinFET

**Table 7: Data for of Transconductance of 8nm and 10nm Channel Length of GaNFinFET**

| Drain Voltage | Transconductance(S/µm) | Transconductance(S/µm) |
|---|---|---|
| V | Transconductance of 8nm channel length of GaNFinFET | Transconductance of 10nm channel length of GaNFinFET |
| 0.10714 | -4.81299E-14 | -1.52158E-14 |
| 0.17857 | 4.66359E-14 | -1.82632E-14 |
| 0.25 | 4.55689E-14 | 2.41893E-14 |
| 0.32143 | 3.95912E-14 | 2.4722E-14 |
| 0.39286 | 3.08032E-14 | 2.3392E-14 |
| 0.46429 | 2.28266E-14 | 1.96345E-14 |

| Table 7: Contd., | | |
|---|---|---|
| 0.53571 | 1.66962E-14 | 1.51061E-14 |
| 0.60743 | 1.27626E-14 | 1.13809E-14 |
| 0.67857 | 9.90615E-15 | 8.71531E-15 |
| 0.75 | 7.9065E-15 | 6.85986E-15 |
| 0.82143 | 6.47582E-15 | 5.55287E-15 |

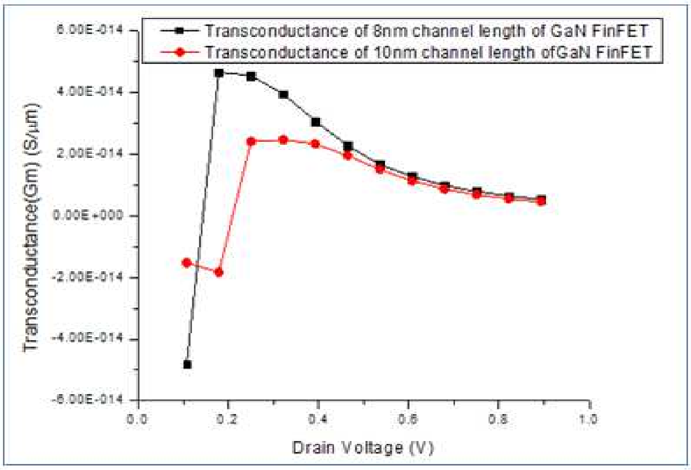


**Figure 8: Comparison of Transconductance of 8nm and 10nm Channel Length of GaNFinFET**

The transconductance is related with electron flow. The transconductance is inversely proportional to resistance. The more resistivity interrupts the current flow. Here in Figure 8, we have seen that the transconductance of 8nm channel length of GaNFinFET has low resistivity for high transconductance, so it generates low interruption for current flow. So, 8nm channel length of GaNFinFET produce sufficient current for nano electrical device. Other hand 10 nm channel length of GaN has more resistivity for low transconductance. So, the 10nm channel length of GaNFinFET makes more interruption of current flow. For better transconductance, we have chosen 8nm channel length of GaNFinFET.

### 5.3. Comparison I-V Characteristic of 8nm and 10nm Channel Length of GaNFinFET

**Table 8: Data for I-V Characteristic of 8nm and 10nm Channel Length of GaNFinFET**

| Gate Voltage | Drain Current(A/µm) | Drain Current(A/µm) |
|---|---|---|
| V | IV Characteristic of 8nm channel length of GaNFinFET | IV Characteristic of 8nm channel length of GaNFinFET |
| 0 | 1.43224E-17 | 6.47112E-19 |
| 0.07143 | 1.53002E-17 | 6.82579E-19 |
| 0.14286 | 1.63014E-17 | 7.18986E-19 |
| 0.21429 | 1.72987E-17 | 7.56277E-19 |
| 0.28571 | 1.82447E-17 | 7.9436E-19 |
| 0.35714 | 1.90787E-17 | 8.33054E-19 |
| 0.42857 | 1.97679E-17 | 8.71975E-19 |
| 0.5 | 2.0317E-17 | 9.10363E-19 |
| 0.57143 | 2.07495E-17 | 9.47032E-19 |
| 0.64286 | 2.10917E-17 | 9.8083E-19 |
| 0.71429 | 2.13665E-17 | 1.01127E-18 |
| 0.78571 | 2.15912E-17 | 1.03854E-18 |
| 0.85714 | 2.17785E-17 | 1.06308E-18 |
| 0.92857 | 2.19375E-17 | 1.08534E-18 |
| 1 | 2.20747E-17 | 1.10567E-18 |

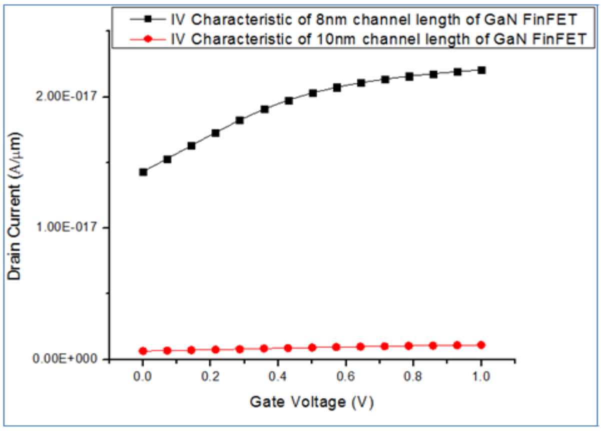


**Figure 9: Comparison of I-V Characteristic of 8nm and 10nm Channel Length of GaNFinFET**

In Figure 9, we have displayed that the curve of I-V characteristic of 8nm channel length of GaN is increased according to high gate voltage other hand the I-V characteristic curve of 10nm channel width for GaN is slowly increased according to high gate voltage. We have shown that 8nm channel length of GaN have better electrical performance than 10nm channel length of GaN. So, the GaNFinFET of 8nm channel length must be used to design a complete electrical nanodevice.

## 6. LIMITATIONS

The limitations of this paper are that the Galliumnitride compounds have mismatch in their lattice constants[4] and also Galliumnitride compounds tend to have a high dislocation density, on the order of a hundred million to ten billion defects per square centimeter [14]. The short channel effect and also the degrading performances of electrical parameters of GaN have been observed by using the channel length less than 8nm. In this paper, we have used only dual gate, 2D device model for proper simulation results.

## 7. CONCLUSIONS

We have tried to find better III-V compound material-based channel by comparing several electrical parameters. We have compared energy band diagram, electric field, transconductance, I-V characteristic and subthreshold swing between GaNFinFET and Si-FinFET by using 8nm channel length. By analyzing the results, we have found that the GaNFinFET of 8nm channel length has had better electrical performances than Si-FinFET of same channel length. Then the impacts of variations of channel length on leakage current for both GaN and Si FinFETs have been successfully shown. We have carefully noticed that the leakage currents by using 8nm and 10nm channel length of GaNFinFET and Si-FinFET. We have observed that the subthreshold swing of 8nm channel length of GaNFinFET at 0.532-0.7625V range of drain voltage is lower than others. So, the lowest subthreshold swing of GaN of 8nm channel length generates more less leakage current which is excellent to design a robust nano device. Finally, transconductance and short channel effects of I-V characteristic of 8nm and 10nm channel length of GaN have been demonstrated. For these better electrical performances, we have suggested to use 8nm channel length of GaNFinFET. In this paper, the more reduced leakage current for 8nm channel length of GaN than the leakage current of silicon as channel material of the same length has been observed, which will be more effective to design powerful nano devices. From overall observations and electrical performances, it has been suggested that 8nm channel length of GaNFinFET will be more effective than that of same length Si-FinFET for future nano devices.

In future, the observed limitations of this research work will be solved by using trigate or gate all around, 3D FinFET device model.

## 8. ACKNOWLEDGEMENT

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